

Jet Fragmentation Functions in pp collisions using SCET

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Outline

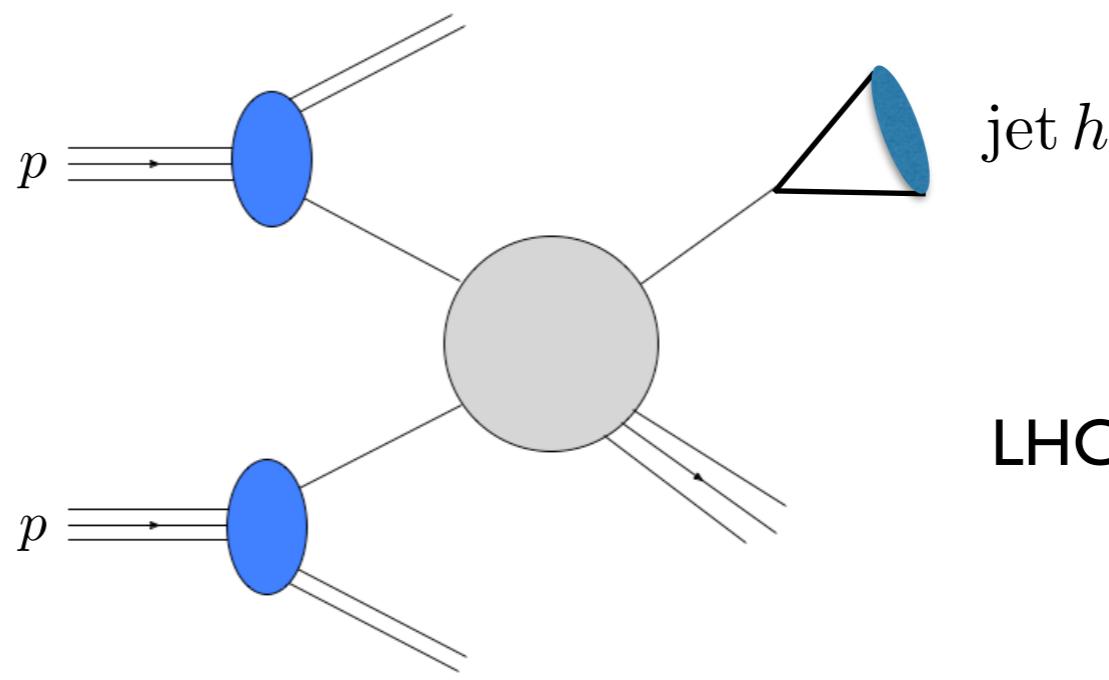
- Jet Fragmentation functions in pp collisions
- EIC *Chien, Kang, FR, Vitev, Xing - '15*
Chien, Kang, FR, Vitev, Xing - in preparation
- Conclusions

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Jet fragmentation function

- Jet substructure observable studying the distribution of hadrons inside a jet
- Probes jet dynamics at a more differential level
- Provides further constraints for fits of fragmentation functions
- Possible studies include spin correlations and
- the modification in heavy ion collisions



LHC, RHIC, Tevatron

Jet fragmentation function

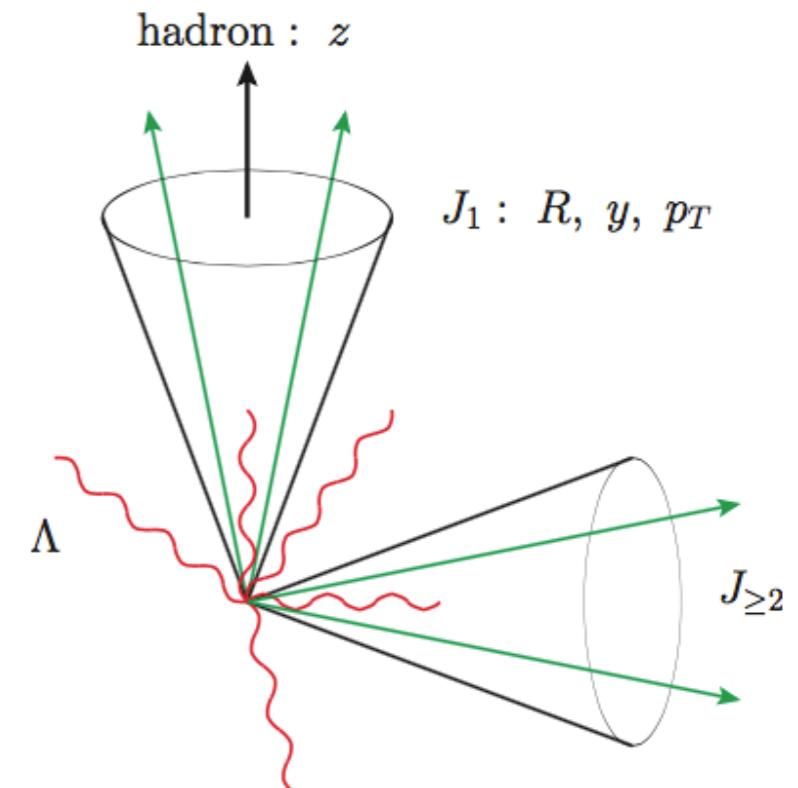
Definition:

$$F(z, p_T) = \frac{d\sigma^h}{dydp_Tdz} / \frac{d\sigma}{dydp_T}$$

where

$$z \equiv p_T^h / p_T$$

It describes the longitudinal momentum distribution
of hadrons inside a reconstructed jet

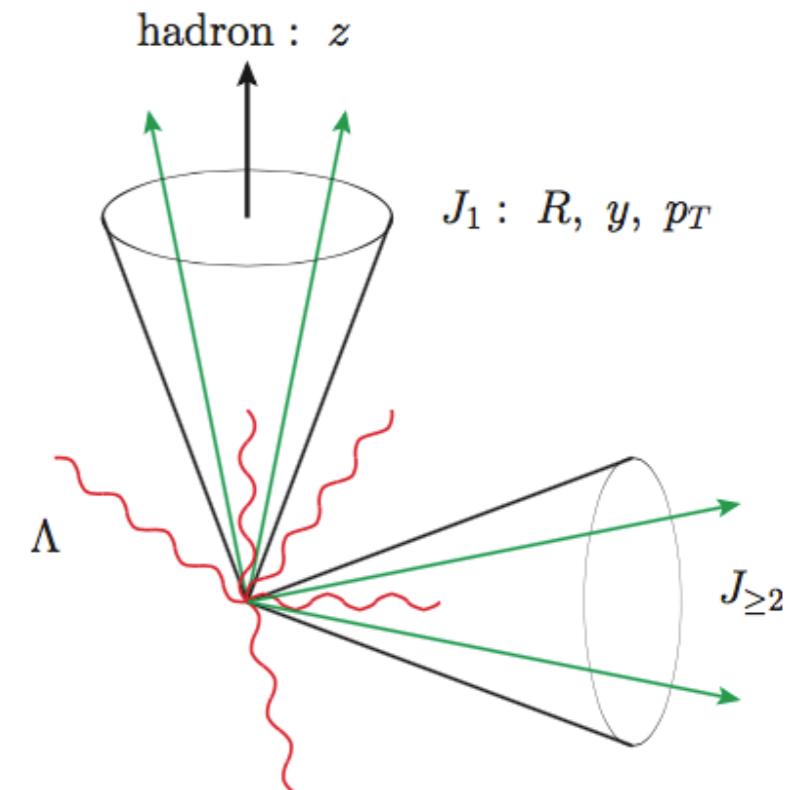


Jet fragmentation function

- Jet fragmentation function studies at NLO

Arleo, Fontannaz, Guillet, Nguyen '14

Kaufmann, Mukherjee, Vogelsang '15



- Fragmenting jet function studies within SCET for e^+e^-

Procura, Stewart '10; Liu '11; Jain, Procura, Waalewijn '11

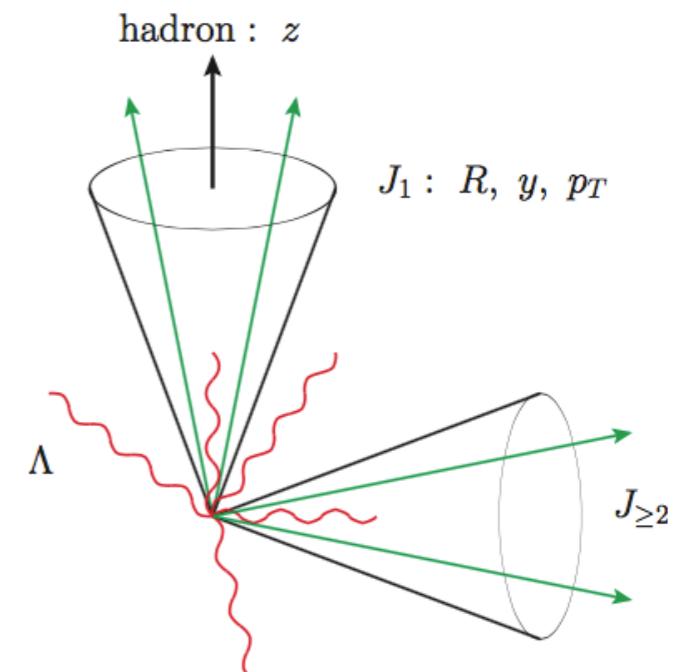
and '12; Procura, Waalewijn '12; Bauer, Mereghetti '14

Jet fragmentation function using SCET

Bauer et al. '00, '01, '02

$$\frac{d\sigma^h}{dy_i dp_{T_i} dz} = H(y_i, p_{T_i}, \mu) \mathcal{G}_{\omega_1}^h(z, \mu) J_{\omega_2}(\mu) \cdots J_{\omega_N}(\mu) S_{n_1 n_2 \cdots n_N}(\Lambda, \mu) + \mathcal{O}\left(\frac{\Lambda}{Q}\right) + \mathcal{O}(R)$$

$$\omega_i = 2p_{T_i}$$



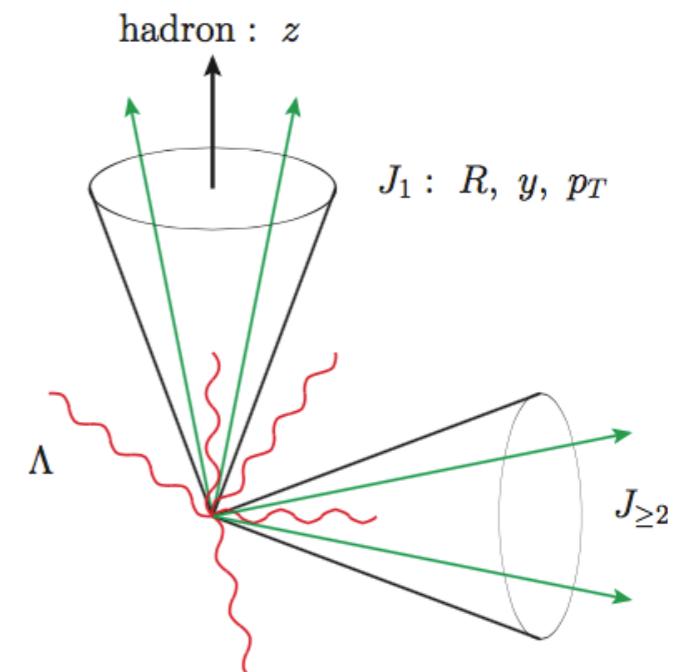
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Jet fragmentation function using SCET

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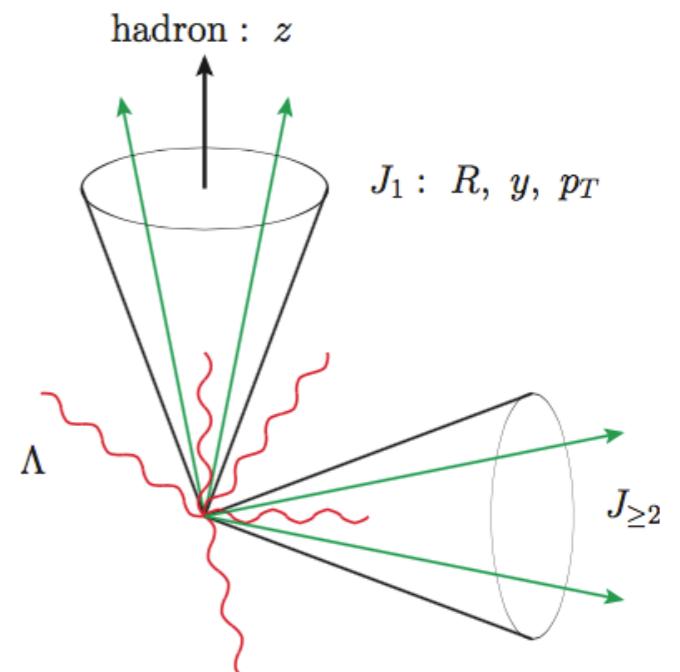
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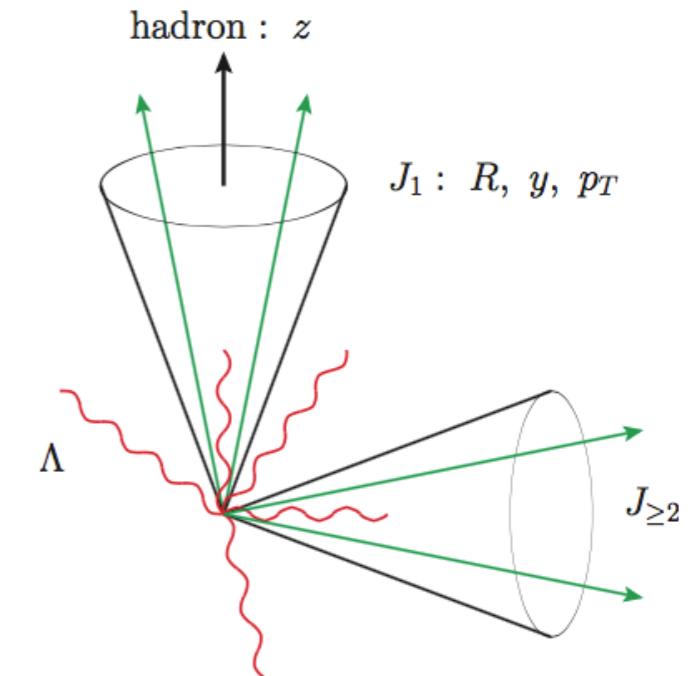
→ $F_{\omega_1}(z, p_{T_i}) = \frac{d\sigma^h}{dy_i dp_{T_i} dz} / \frac{d\sigma}{dy_i dp_{T_i}} = \frac{\mathcal{G}_{\omega_1}^h(z, \mu)}{J_{\omega_1}(\mu)}$

$$F(z, p_T) = \frac{1}{\sigma_{\text{total}}} \sum_{i=q,g} \int_{\text{PS}} dy dp_{T'} \frac{d\sigma^i}{dy dp_{T'}} \frac{\mathcal{G}_i^h(\omega, R, z, \mu)}{J^i(\omega, R, \mu)}$$



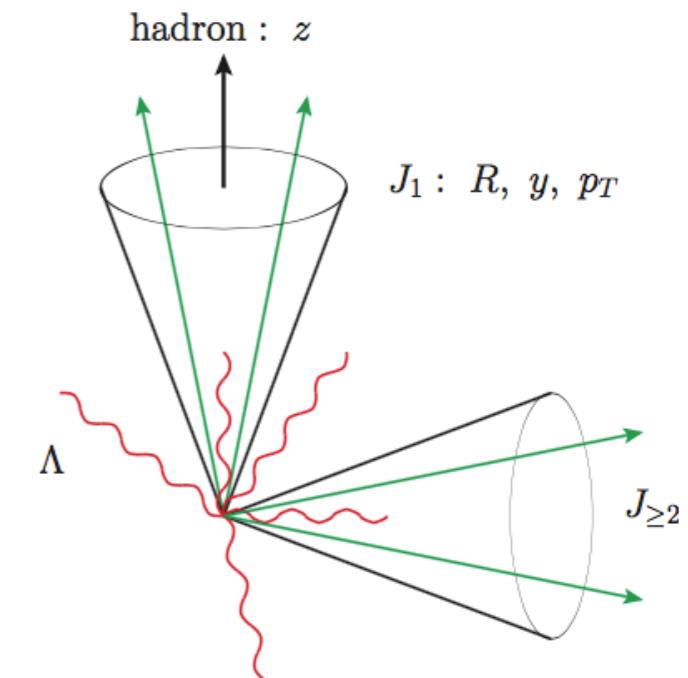
Fragmenting jet function using SCET

- The jet invariant mass m_J^2 is measured
- Jet algorithms impose constraint on m_J^2
- Matching onto standard FFs $D_j^h(z, \mu)$ for $m_J^2 \gg \Lambda_{\text{QCD}}^2$



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$$\mathcal{G}_i^h(\omega, R, z, \mu) = \sum_j \int_z^1 \frac{dx}{x} \mathcal{J}_{ij}(\omega, R, x, \mu) D_j^h\left(\frac{z}{x}, \mu\right) + \mathcal{O}\left(\frac{\Lambda_{\text{QCD}}^2}{\omega^2 \tan^2(R/2)}\right)$$



Matching coefficients

Fragmentation functions

Fragmenting jet function using SCET

Quark FJF at 1-loop:



Fragmenting jet function using SCET

Quark FJF at 1-loop:



$$\mathcal{J}_{qq}(\omega, R, z, \mu) = \delta(1-z) + \frac{\alpha_s}{\pi} C_F \left[\delta(1-z) \left(L^2 - \frac{\pi^2}{24} \right) + \hat{P}_{qq}(z)L + \frac{1-z}{2} + \hat{\mathcal{J}}_{qq}^{\text{alg}}(z) \right]$$

where

$$L = \ln \frac{\omega \tan(R/2)}{\mu}$$

$$\hat{\mathcal{J}}_{qq}^{\text{anti-}\mathbf{k}_T} = \hat{P}_{qq}(z) \ln z + (1+z^2) \left(\frac{\ln(1-z)}{1-z} \right)_+$$

$\overline{\text{MS}}$ scheme

Resummation

RG equation

$$\mu \frac{d}{d\mu} \mathcal{G}_i^h(\omega, R, z, \mu) = \gamma_{\mathcal{G}}^i(\mu) \mathcal{G}_i^h(\omega, R, z, \mu)$$

→ Resummation

$$\mathcal{G}_i^h(\omega, R, z, \mu) = \mathcal{G}_i^h(\omega, R, z, \mu_{\mathcal{G}}) \exp \left[\int_{\mu_{\mathcal{G}}}^{\mu} \frac{d\mu'}{\mu'} \gamma_{\mathcal{G}}^i(\mu') \right]$$

with:

$$\gamma_{\mathcal{G}}^i(\mu) = \Gamma_{\text{cusp}}^i(\alpha_s) \ln \frac{\mu^2}{\omega^2 \tan^2(R/2)} + \gamma^i(\alpha_s)$$



anomalous dimensions:

$$\Gamma_{\text{cusp}}^i = \sum_n \Gamma_{n-1}^i \left(\frac{\alpha_s}{4\pi} \right)^n$$

$$\gamma^i = \sum_n \gamma_{n-1}^i \left(\frac{\alpha_s}{4\pi} \right)^n$$

→ Resummation of $\ln R$

Resummation

FJF:

$$\mathcal{G}_i^h(\omega, R, z, \mu) = \mathcal{G}_i^h(\omega, R, z, \mu_{\mathcal{G}}) \exp \left[\int_{\mu_{\mathcal{G}}}^{\mu} \frac{d\mu'}{\mu'} \gamma_{\mathcal{G}}^i(\mu') \right]$$

Unmeasured jet function: $J^q(\omega, R, \mu) = 1 + \frac{\alpha_s}{\pi} C_F \left[L^2 - \frac{3}{2}L + d_J^{q,\text{alg}} \right]$

with

$$L = \ln \frac{\omega \tan(R/2)}{\mu}$$

$$d_J^{q,\text{anti-k}_T} = \frac{13}{4} - \frac{3\pi^2}{8}$$

Resummation

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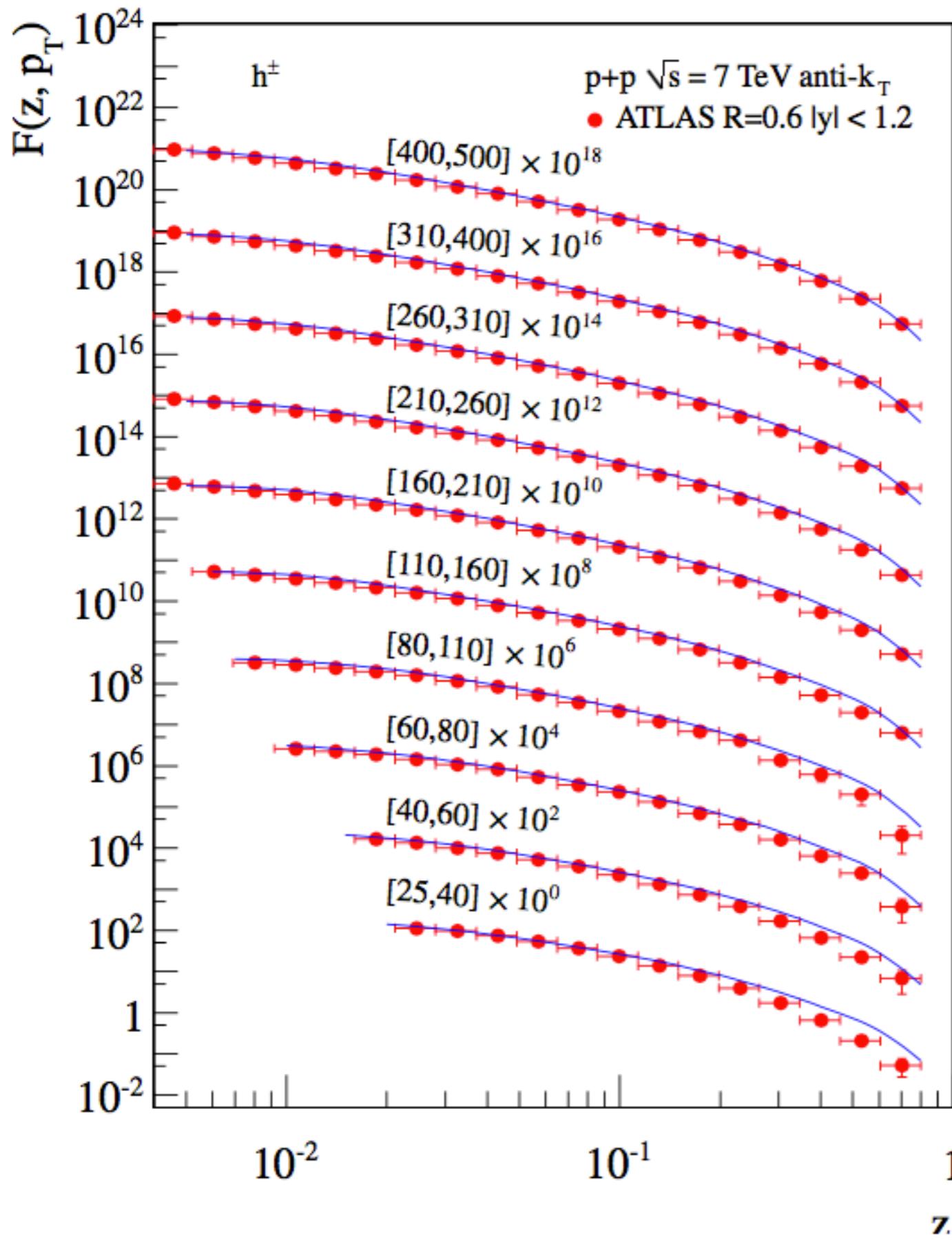
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$$\gamma_{\mathcal{G}}^i(\mu) = \gamma_J^i(\mu)$$

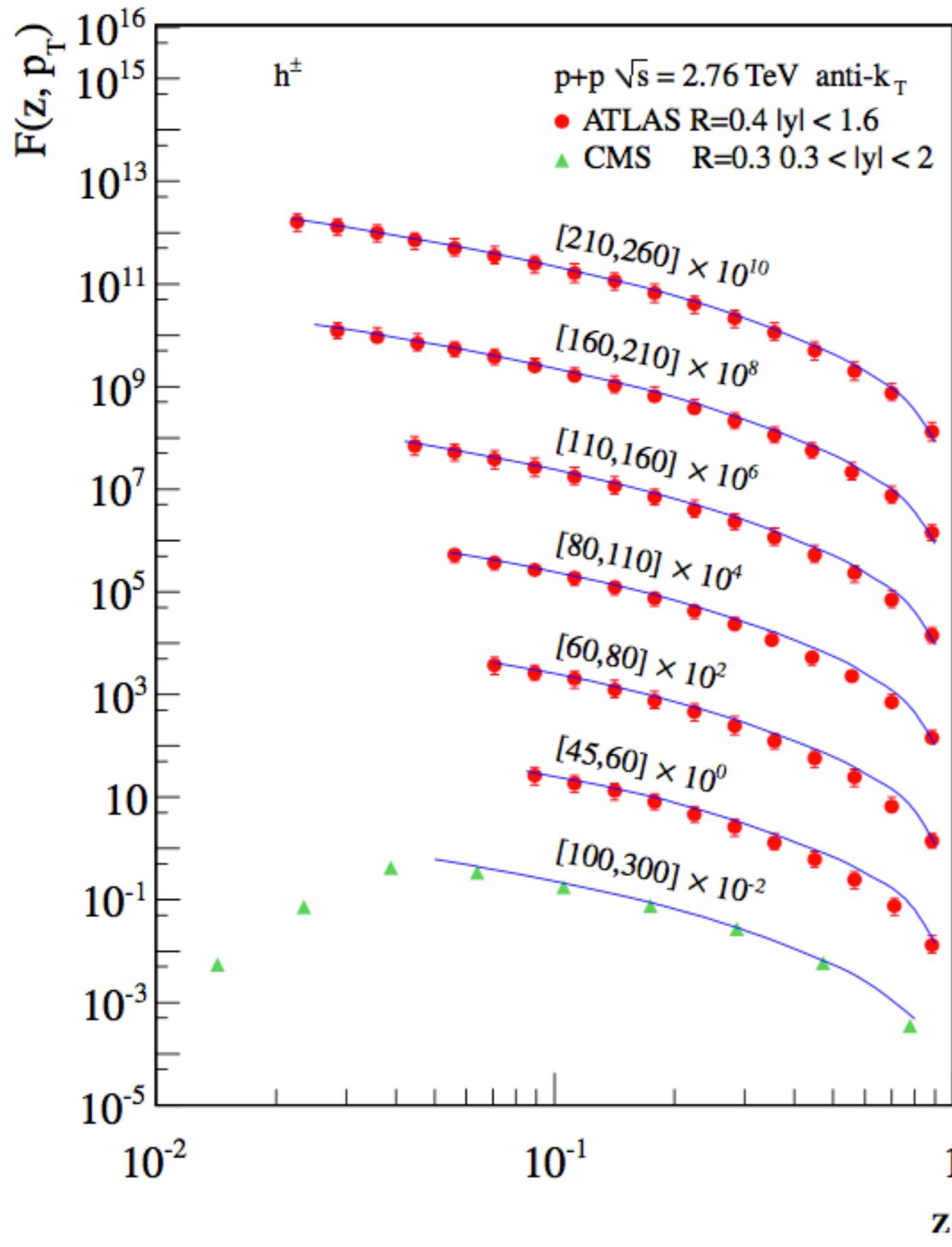
→ $F_{\omega_1}(z, p_{T_i}) = \frac{\mathcal{G}_{\omega_1}^h(z, \mu)}{J_{\omega_1}(\mu)}$ is RG-invariant for $\mu_J \sim 2p_T \tan(R/2)$!



Comparison to ATLAS data
at $\sqrt{s} = 7 \text{ TeV}$

Light charged hadrons $h = h^+ + h^-$

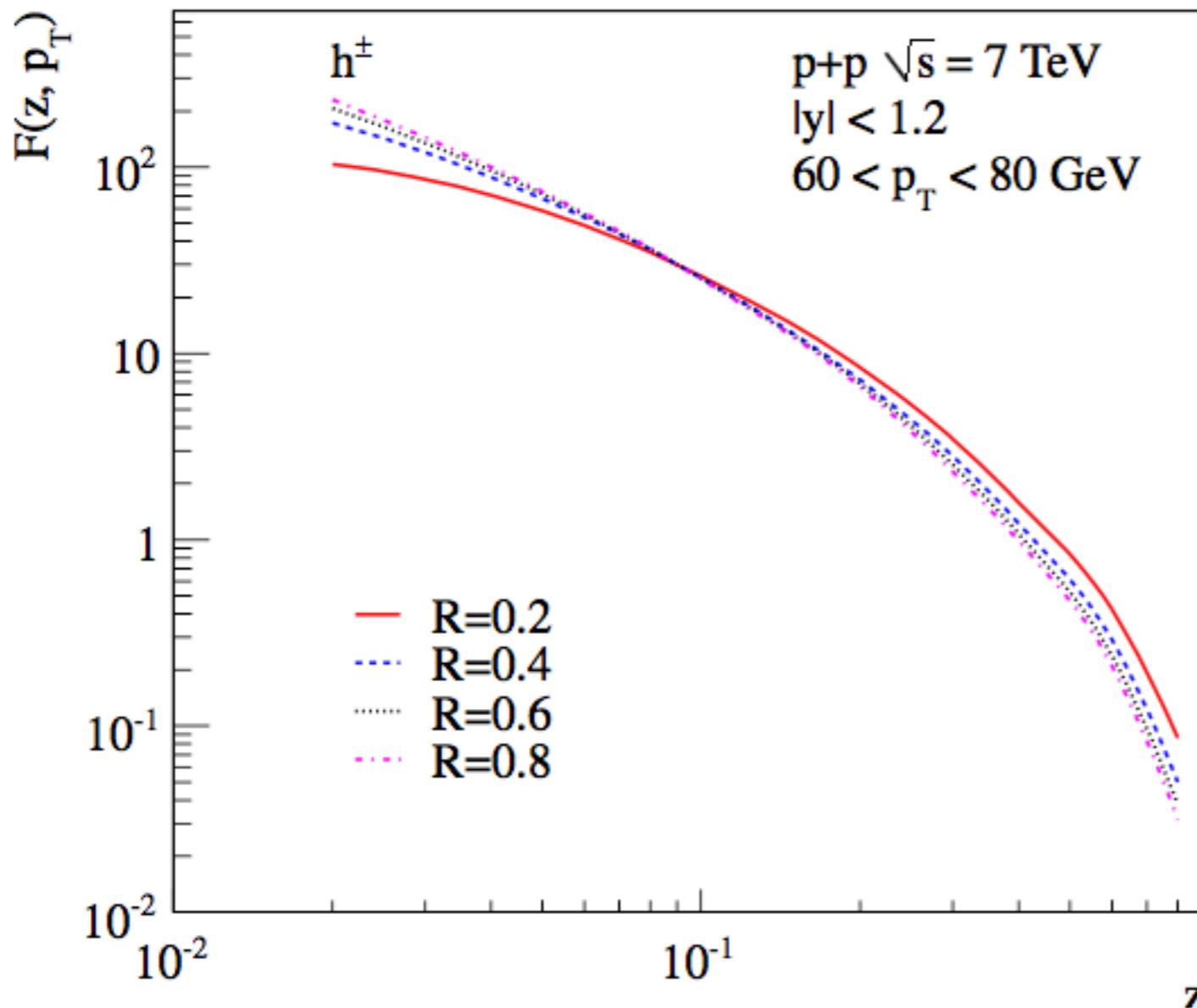
Using DSS FFs
de Florian, Sassot, Stratmann - '07



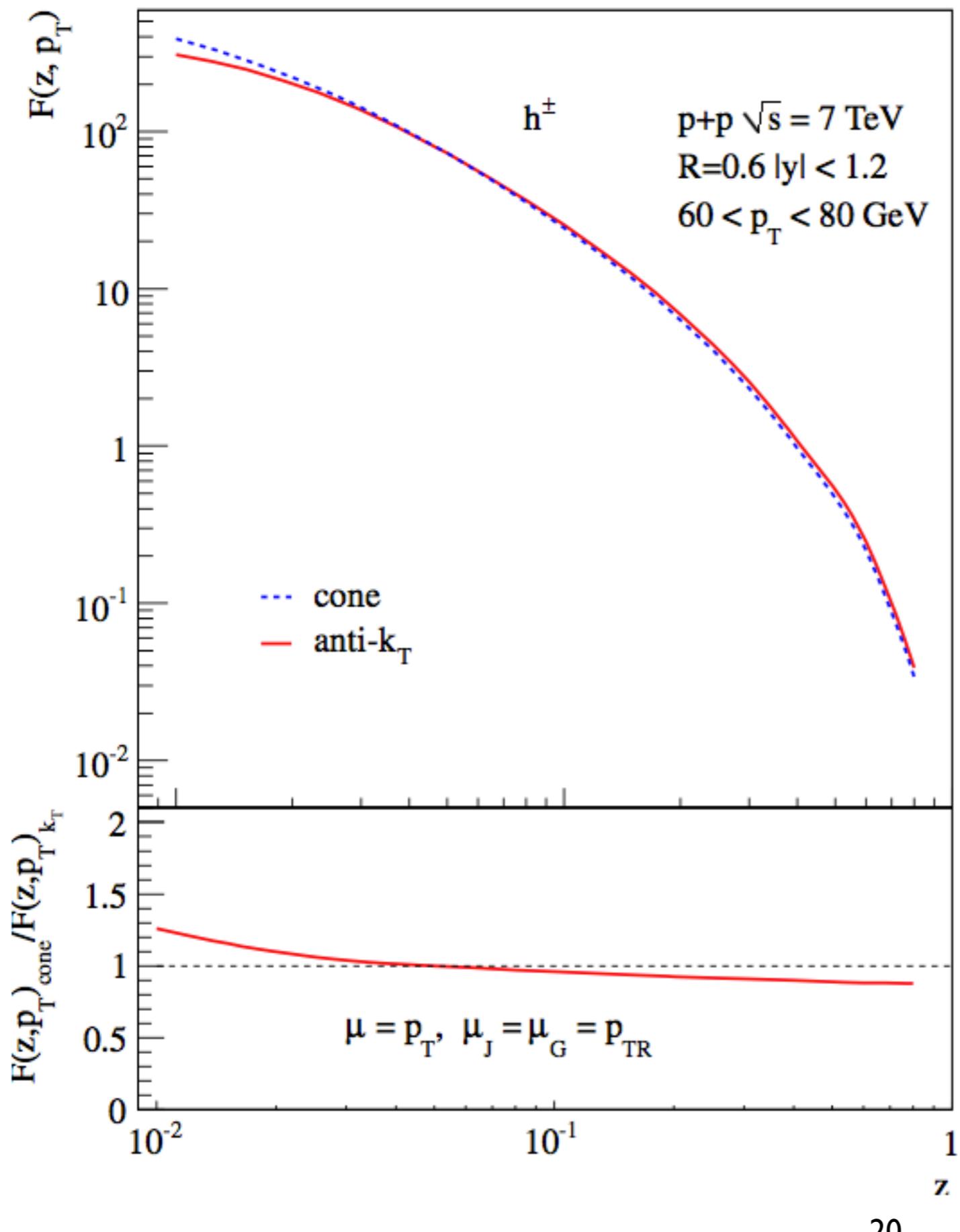
Comparison to ATLAS and CMS
data at $\sqrt{s} = 2.76 \text{ TeV}$

Light charged hadrons $h = h^+ + h^-$

Using DSS FFs
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Jet parameter R
dependence



Jet algorithm
dependence: cone, anti- k_T

Resummation of large logarithms

Convolution structure:

$$\mathcal{G}_i^h(\omega, R, z, \mu) = \sum_j \int_z^1 \frac{dx}{x} \mathcal{J}_{ij}(\omega, R, x, \mu) D_j^h\left(\frac{z}{x}, \mu\right) + \mathcal{O}\left(\frac{\Lambda_{\text{QCD}}^2}{\omega^2 \tan^2(R/2)}\right)$$

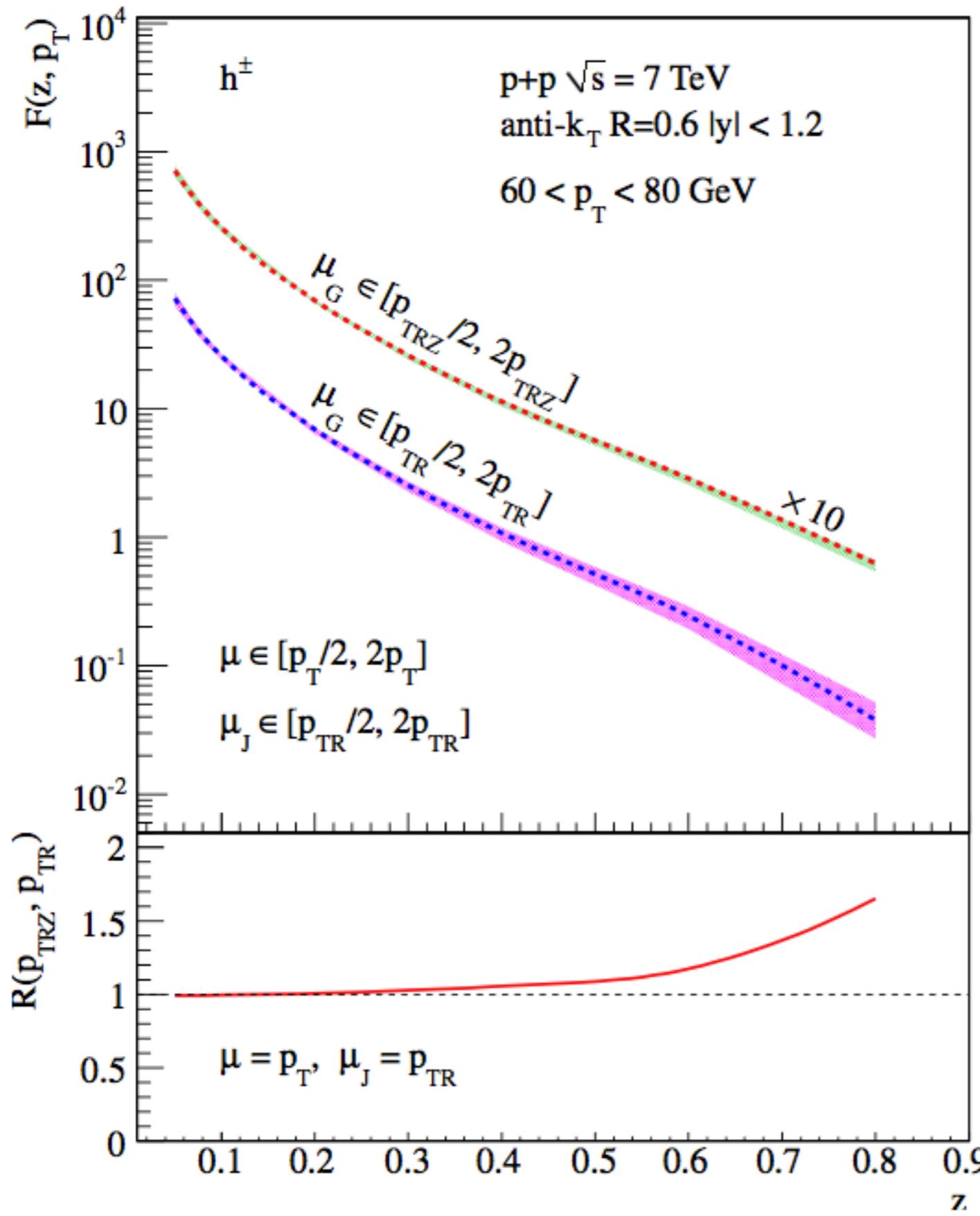


Threshold logarithms $\left(\frac{\ln(1-x)}{1-x}\right)_+$ become large at the partonic threshold $x \rightarrow 1$

$$\longrightarrow \mathcal{G}_q^h(\omega, R, z, \mu) = \left\{ 1 + \frac{\alpha_s}{\pi} C_F \left[\ln^2 \left(\frac{\omega \tan(R/2)(1-z)}{\mu} \right) - \frac{\pi^2}{24} \right] \right\} D_q^h(z, \mu) + \dots$$

Choosing $\mu = \omega \tan(R/2)(1-z)$ resums logarithms of R and $(1-z)$

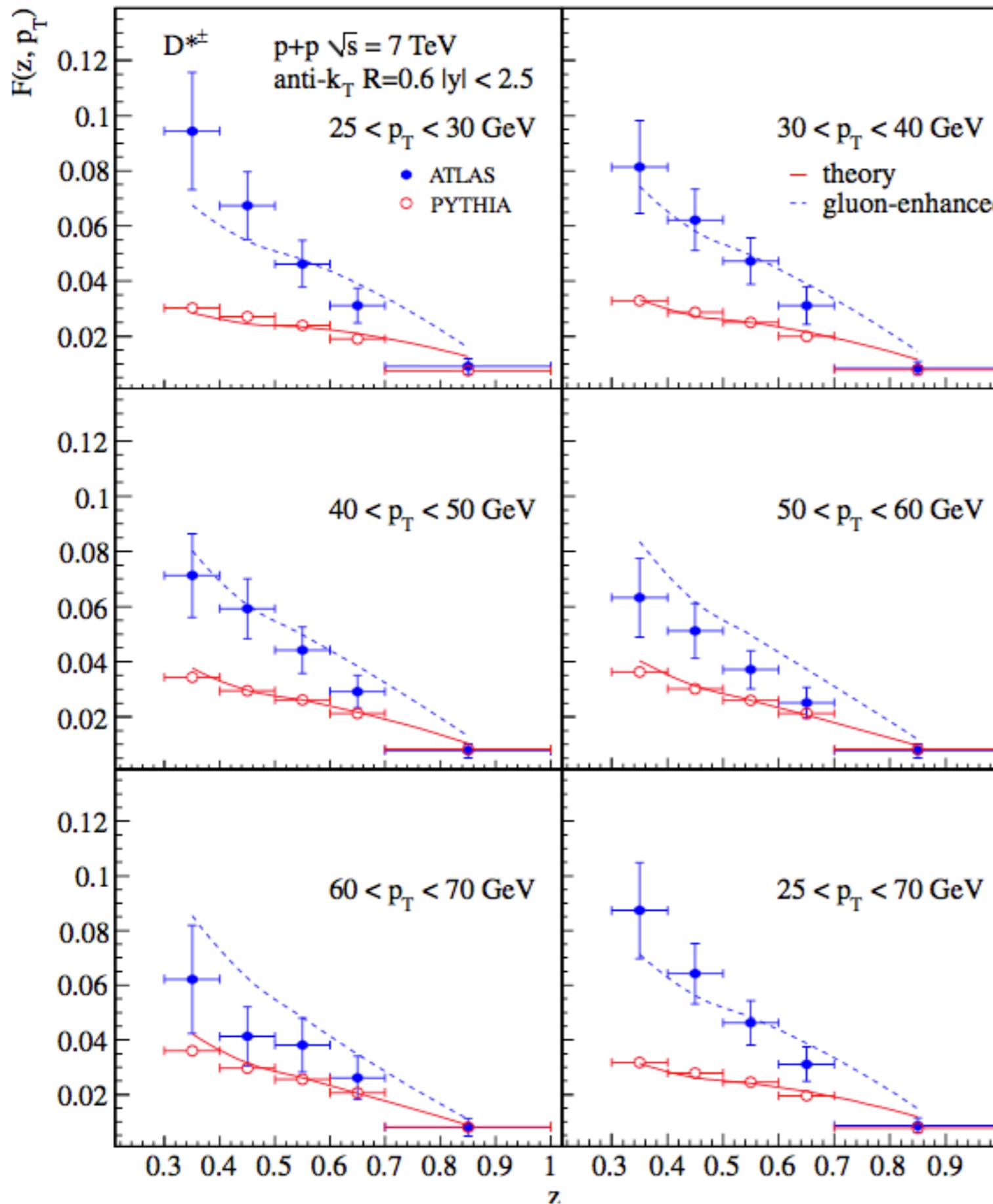
see also Procura, Waalewijn '12



$\ln(1 - z)$ resummation dependence

Both $\ln R$ and $\ln(1 - z)$ are simultaneously resummed

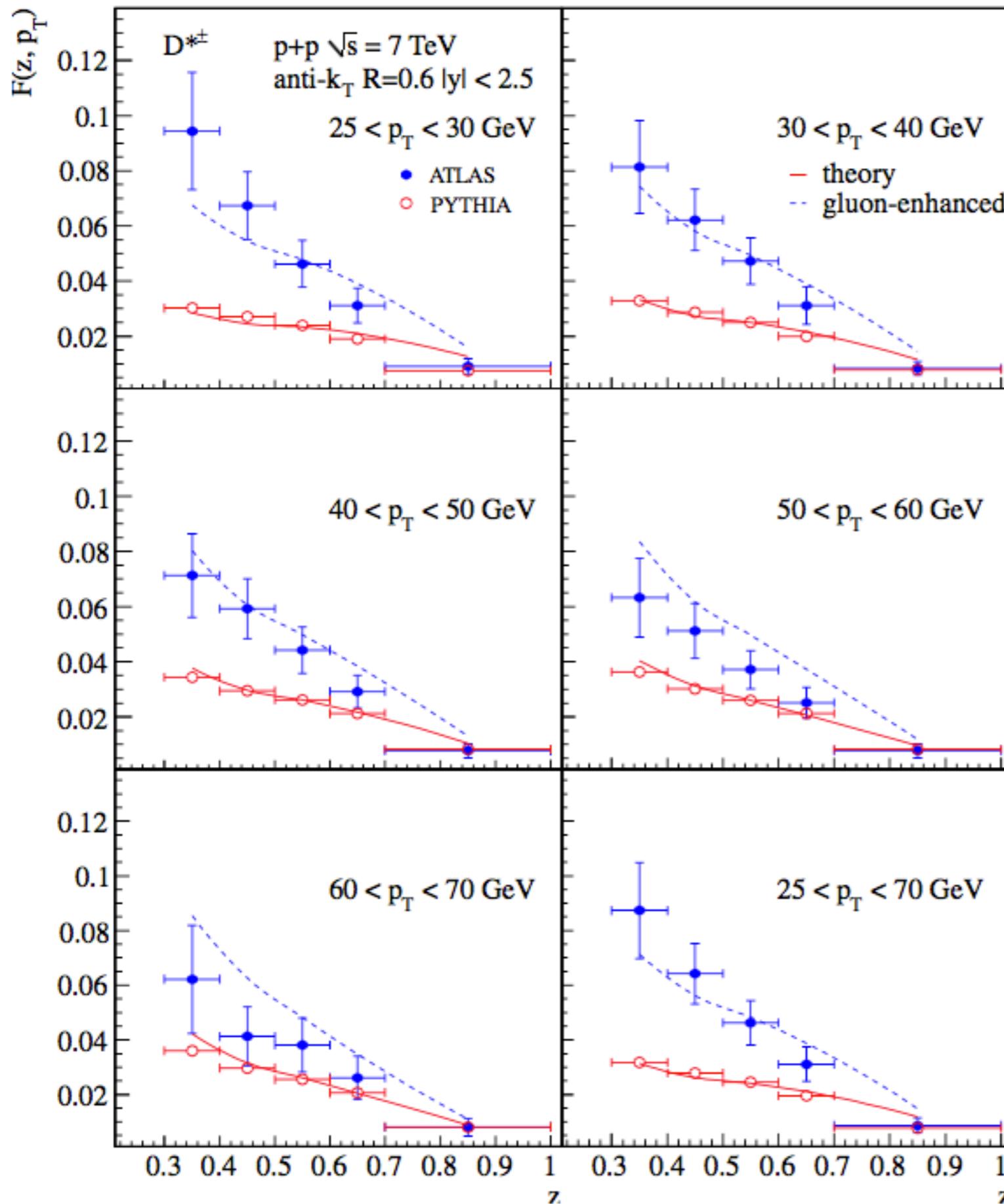
Hadronic threshold $z \rightarrow 1$



D-meson
jet fragmentation function

Comparison to ATLAS data
and PYTHIA simulations
at $\sqrt{s} = 7 \text{ TeV}$

Using FFs from
Kneesch, Kniehl, Kramer, Schienbein - '08



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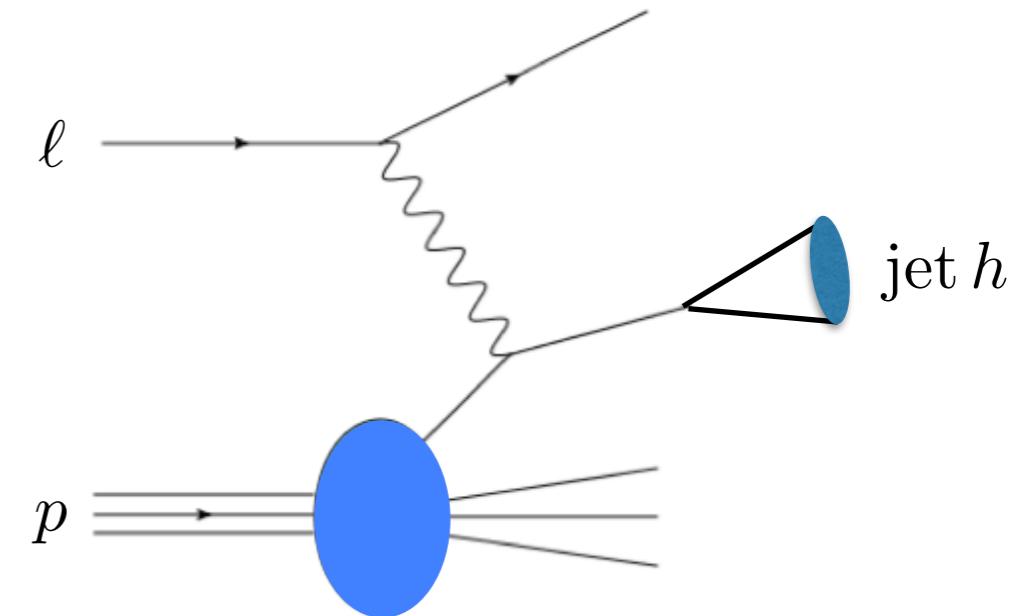
— · — $D_g^D(z, \mu) \rightarrow 2 D_g^D(z, \mu)$

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Jet fragmentation functions at the EIC

- Jet substructure observables for the EIC
- High luminosity + PID
- ℓp as a baseline measurement for eA



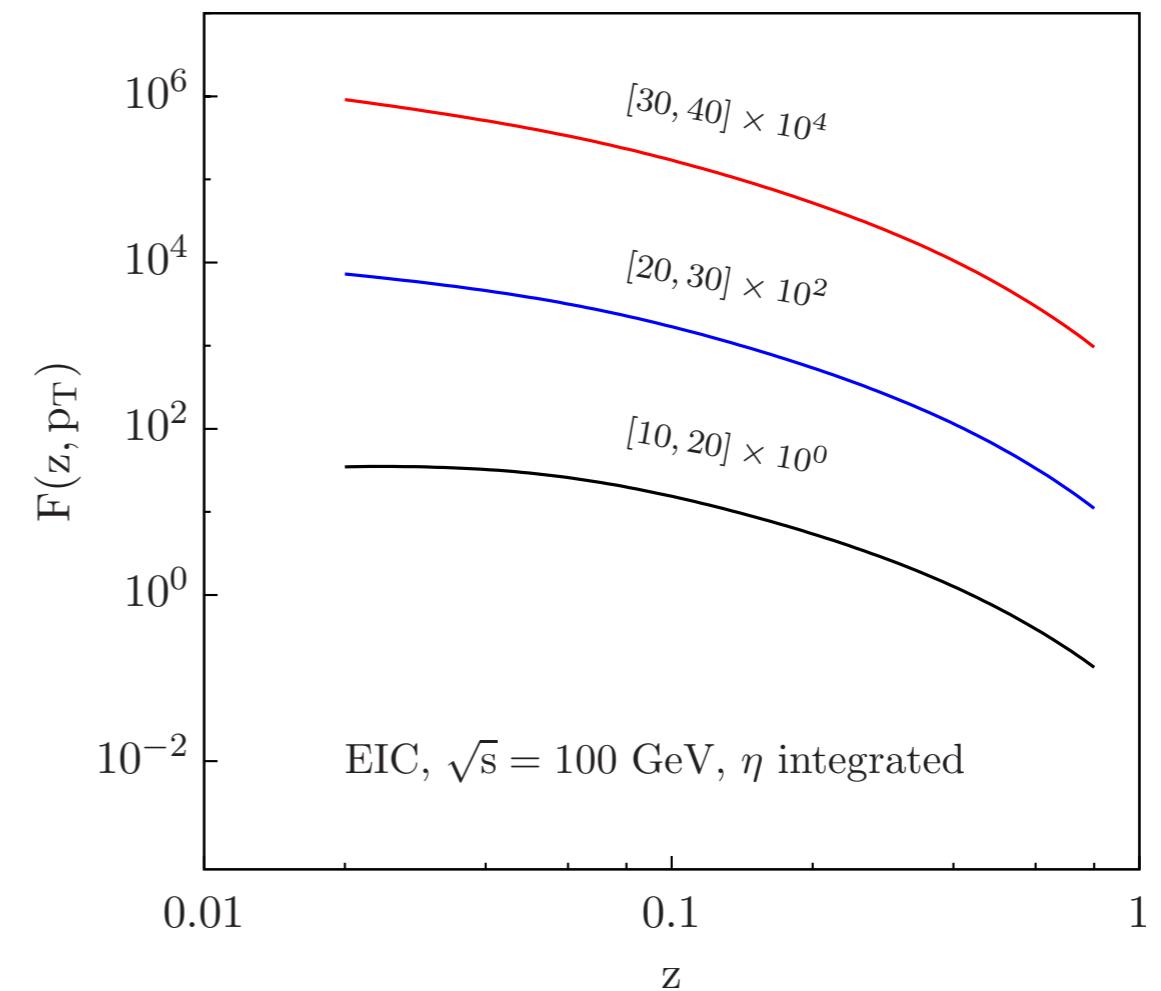
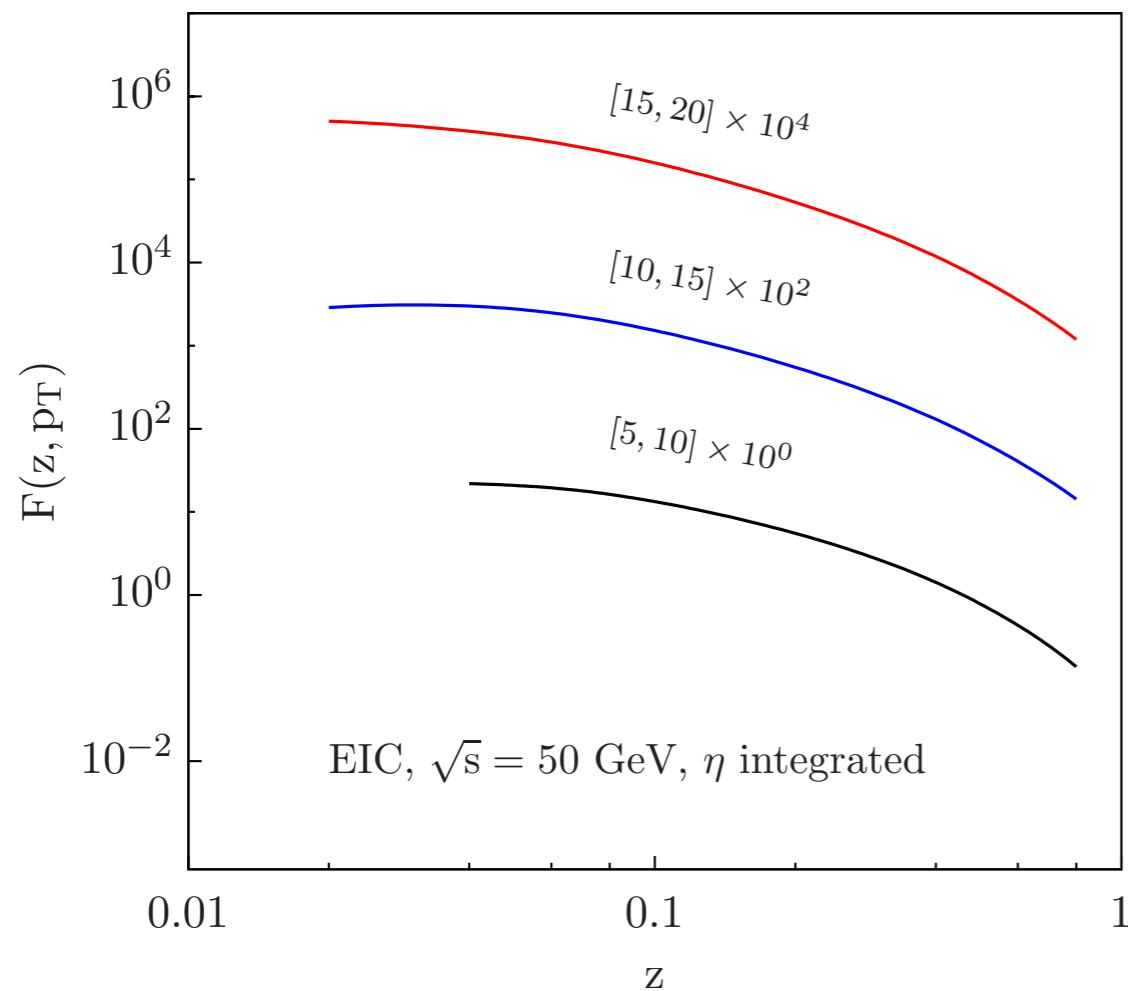
- Simplest example: $\ell p \rightarrow (\text{jet } h) + X$

final state lepton remains unobserved

Kang, Metz, Qiu, Zhou - '11
Hinderer, Schlegel, Vogelsang - '15

Numerical results

Light charged hadrons $h = h^+ + h^-$ in $\ell p \rightarrow (\text{jet } h) + X$



Using DSS FFs

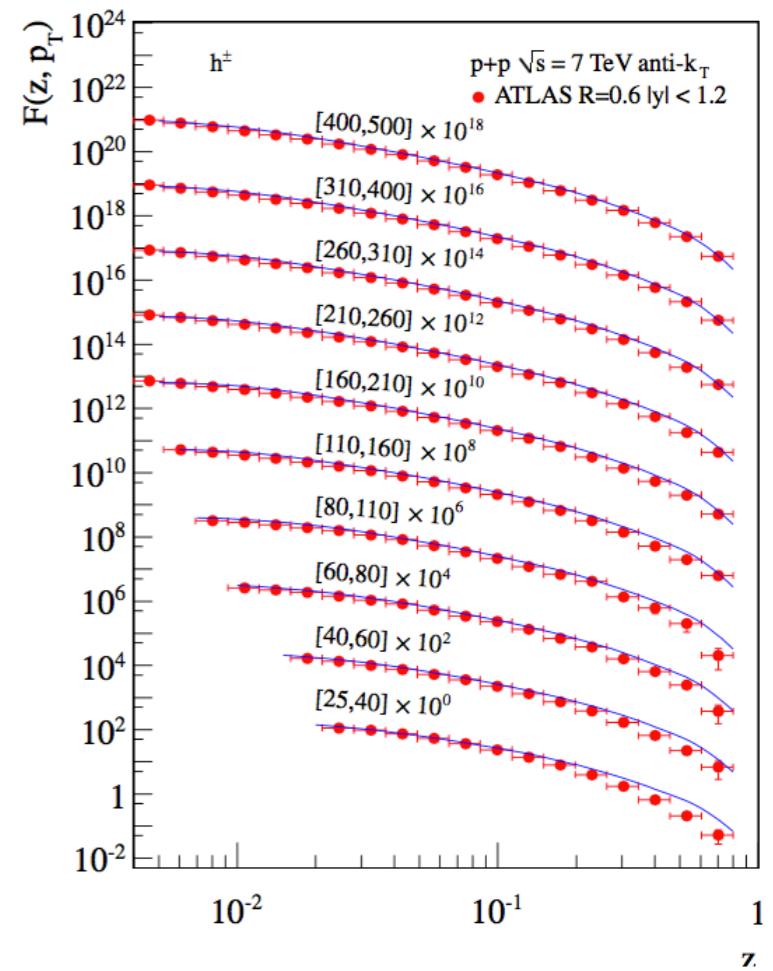
de Florian, Sassot, Stratmann - '07

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Conclusions

- Jet fragmentation function for light hadrons and heavy mesons
 - Algorithm, radius dependence, and theoretical uncertainty
 - Resummation
 - First numerical results for the EIC
-
- Threshold and small-z resummation
 - Extension to processes where the lepton is observed
 - Extension to Pb+Pb and eA



backup

Accuracy of Resummation

$$\mathcal{O}(\alpha_s^k) : \quad C_{kn} \times \alpha_s^k \ln^n \bar{N}, \quad \text{where } n \leq 2k$$

Fixed Order

LO	1					
NLO	$\alpha_s L^2$	$\alpha_s L$	α_s			
NNLO	$\alpha_s^2 L^4$	$\alpha_s^2 L^3$	$\alpha_s^2 L^2$	$\alpha_s^2 L$	α_s^2	
...	
$N^k LO$	$\alpha_s^k L^{2k}$	$\alpha_s^k L^{2k-1}$	$\alpha_s^k L^{2k-2}$	$\alpha_s^k L^{2k-3}$	$\alpha_s^k L^{2k-4}$...

↓ ↓ ↓

LL NLL NNLL

$$L = \ln \bar{N}$$